Cognitive Analysis of Pedestrians Walking While Using a Mobile Phone

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The purpose of this study is to examine the effects of EEG signals on different cognitive tasks of the pedestrians. The author developed new software for simulation, called Pedestrian 3D virtual simulator which considered in detail the decision-making cognitive tasks of pedestrians, with simultaneous measurement of the EEG signals. Two walking sessions were designed: one receiving the SMS while walking, the other involved replying SMS while walking. Fifty subjects participated in the study. Based on the Singular Value Decomposition algorithm the EEG was considered to analyze of features. The results of this study show that it was determined that the right frontal lobes were active in distractions when pedestrians while walking. EEG changes during the tasks were seen in alpha 1 and alpha 2 bands substantial changes were observed in F1, FZ, F2 channels. The use of mobile phones (especially replying SMS) while walking negatively affected the perception of pedestrians, putting them at a risk for accidents, suggesting the need for interventions to decrease the use of mobile phones while walking. One of the most important results of the study is that an ongoing response is recorded in the middle of the prefrontal cortex in those who are careless walking.

Keywords: Pedestrian Walking; EEG; Cognitive Control; Pedestrian Behavior
1. Introduction

Attitudes and behaviors of individuals affect the crowd and hence the communities, accordingly, pedestrian movements have been frequently investigated in recent years. The walking behavior of pedestrians can be controlled and organized to enable the prediction of “where to walk” and “how to walk” on the streets of towns; these can be used in processing and architectural design. Therefore, in situations that are of interest to communities, such as during safe evacuation systems and mass walking, it is very important to know and predict pedestrian movements, but generally, studies have been limited to micro- and macro-simulation methods. Apart from the existing methods of analysis, brain science will be more important to analyze pedestrian movements, as well as crowd movements, because these activities include continued brain processes, as simultaneous problem-solving or decision making behaviors. The analysis of pedestrian movements using brain sciences has led to a „search for the cause of people’s movements.“ Cognitive brain sciences can be regarded as one of the most accurate points of this analysis. In this case, support from brain imaging techniques (such as Electroencephalogram, Magnetoencephalography, etc.), cognitive sciences into the work of the pedestrian movements will make it easier to gain meaning. Because it is necessary to understand their movements in order to investigate their behavior. Electroencephalography (EEG) systems are a brain analysis system in which these behaviors can be investigated.

EEG is a neurophysiological measurement of electrical activity in the brain and is recorded from electrodes placed in the scalp (Yang et al., 2011). The first recording of the electrical activity of the human brain was done in 1924 by the German psychiatrist, Hans Berger (Teplan, 2002). EEG also called spontaneous activity, has amplitudes of approximately 100 μV when measured on the scalp and approximately 1–2 mV when measured on the brain surface (Rush and Driscoll, 1969; Puikkonen and Malmivuo, 1987).

Much more potentials are the components of EEGs’ signals and occur in response to a visual or auditory stimulus. EEG signals are often found under noisy conditions, and these potentials can be distinguished by signal averages. An EEG based brain–computer interface (BCI) system
automatically extracts specific features of these signals and uses these to operate computer controlled devices (Pfurtscheller et al., 2006). The BCI system is composed of the following units: brain activity measurement (data acquisition), signal preprocessing, feature extraction, and classification. Through the BCI systems, many different events can be analyzed in the brain and also can be organize these features and generates control signals for an output device, which can be a robotic arm, neuroprosthesis, or monitor. Subjects learn from experiences when using the device, and EEG features are enhanced; this is a feedback that closes the loop of the BCI system.

Many cognitive cases can be detected and interpreted by these systems. Many cases can be analyzed by EEG systems, from the mood determination of the elderly people in the urban environment (Tiley et al., 2017) to the behavior of the drivers (Jap et al., 2009; Simon et al., 2011; Erkan and Erkan, 2016; Guo et al., 2016). In recent years, EEG systems have been used for cognitive-behavioral situations (Yang et al., 2011; Courtney and Polich, 2010) besides sleep treatments. In many parts of the world, the carelessness of pedestrians causes persistent accidents. Considering only pedestrian carelessness, the number of deaths in Turkey was 12,000 in 2013 (TSI, 2014) and continues to increase every year. Many external factors contribute to the carelessness of pedestrians, such as cell phone (including talking) distraction while walking, incorrect placement of striking urban furniture, unplaced signs in dense traffic areas and also wrong architectural design principles. “The number of mobile phones in the United States has increased from 340,000 in 1985 to 302.9 million in 2013” (TWA, 2013). This increasing number of mobile phones cannot be prevented, and because of rapid developments over the last 30 years, new technology and mobile phones stand out among people. Figure 1 shows the CPSC-estimated cumulative pedestrian injuries from 2004 to 2010 by age (Nasar and Troyer, 2013).
Figure 1. CPSC national estimates of person injuries related to mobile phone use by age (n = 5482) (Nasar and Troyer, 2013).

In Figure 1, As Nasar and Troyer (2013) stated that the study’s subject played an important role in the election, a group of mobile phone users between 16 and 25 years of age, and the pedestrians who faced „a different threat“ provided important data. There are many external factors other than use of mobile phones that distract pedestrians (e.g., drivers). Attention is distributed on two main factors:

- Visual Distraction
- Cognitive Distraction

Visual distractions are physical barriers on the path of walking pedestrians that prevent vehicles on the street from being noticed, whereas cognitive distractions are not mentally noticed. Visual and cognitive distractions interact with each other to pose very dangerous risks to pedestrians (Kaber et al., 2012). Anderson (1990) stated that the general definitions of both are considered to decrease mental concentration on a specific task. In addition to studies on the distribution of attention in pedestrians, studies on factors that affect EEG measurements of brain activity are available in literature (Lin et al., 2009; Debener et al., 2012).
Literature studies, besides the different types of accidents, also emphasize “accidents caused by pedestrians“ (Kouabenan & Guyot, 2004; Zhang et al., 2014; Martinez et al., 2016). For this reason, many studies are the first priority of broadcasts is their security. The inattentiveness of pedestrians negatively affects both pedestrian and vehicle access. The primary condition for the prevention of pedestrian accidents is to understand their movements. The two main purposes of this study were to

- Determine by EEG signals the cognitive changes that receiving and replying SMS while walking.
- Cognitive changes on the brain lobes of pedestrians’ walking in different situations were investigated.

2. Materials and Methods

2.1. Participants
The study population consisted of 18–25-year-old students at Süleyman Demirel University (n=50; 30 males=22, 34 years old), 20 females=21, 12 years old; SD=4.30) who voluntarily participated in this study. No participant had a pertinent medical history and psychiatric issues. All participants were adequately informed before the experiment. The experiment was carried out in the entire faculty of architecture in Süleyman Demirel University.

2.2. 3D Virtual Street Design
The Pedestrian 3D virtual simulator (PDVS) has been developed to easily analyze the movements of the pedestrians. The PDVS with computerized virtual reality-based city environments was operated as a practical measure of pedestrian walking. PDVS was created by C++ and supported 3D design programs. A short demo video of the street scenario is shown in Figure 2.

The PDVS was created by Süleyman Demirel University Faculty of Architecture students. Real urban pedestrian streets were modeled in the simulator. In this model, the urban design elements of Turkey’s four major cities (Ankara, Antalya, Istanbul, and Izmir) were taken into consideration. Pedestrians walking in the area were provided with vehicles, crowds, other landscape elements, and urban furniture (seating areas, garbage cans, etc.).
Pedestrians could change their direction and speed from the keyboard; they were able to move and cross the street in a field of different urban elements. Vehicles or other pedestrians approaching could be followed by the simulator. Also, the simulator was designed in such a way that walking pedestrians could simultaneously use their cell phones (texting, internet connection, telephone interview, etc.). No participant had any experience on PDVS, so before the experiment, subjects was allowed to navigate for 5 minutes on PDVS.

2.3. Procedure
As shown in Figure 2, Visual City Street was created in this study. Proper conditions were created for the subjects who were 75 cm away from the screen. The average walking speed was determined to be 1 m/sec, with a consideration that these rates could change anytime. Participants are moving at a constant speed without changing their speed. In this environment, PDVS enabled the participants to feel like they were on the usual streets of the city. Realistic renderings have been provided to enable participants to directly interacting with the 3D environment and ensure that realistic walking conditions during experiments. Participants were asked to walk as they would in 3D streets (PDVS). During their walk, all the conditions of transportation and walking with careful attention are given. The experiment was completed in total 15 minutes. 5 SMS have been sent to each participant in 3D streets (Task_1). The contents of SMS are shown in Appendix-A.
Participants were asked to reply to these SMSs and to walk during this time (Task_2). The moments that they “read that called Task-1” and “reply that called Task-2” to were recorded separately. Simulation experiences were divided into three segments (just walking, walking with receiving and read to SMS, and walking with reply to SMS) for analysis. Pedestrian behavior is divided into two classes based on the movements on the street where they walk: Normal walking and distracted walking.

2.4 Apparatus
The 32 channel EEG device has been used in this experiment. The EEG channels have been placed according to the international standard 10-20 system as Figure 3.

Prior to the experiment, the contact impedance between the EEG electrodes and the cortex was calibrated to be less than 5 kΩ as Lin et al. (2005) and Wu et al. (2004). The EEG data was recorded at 500 Hz for resampling, and then reduced to 250 Hz.

Most cognitive activities occurred in the frontal lobe (Fuster, 2002; Stuss, 2002; Lin et al., 2009). Since the frontal lobe has cognitive functions such as decision making, the study was built on it and the alignment of the electrodes was made accordingly.
2.5. Data Process

EEG data were processed by removing participants’ finger movements and eye blinks. The EEG data were synthesized by muscles and other movements were corrected by the method of Gratton (Gratton et al., 1983). In this study, the author used singular value decomposition to extract EEG data for further analysis with MATLAB as Lagerlund et al. (1997).

3. Results

In this study, to examine the brain science of pedestrians who walk while using cell phones and concretely analyzed serious consequences that arise from this distraction. It also examines changes in EEG signals and frontal lobes of cognitive changes in the „SMS receiving“ and „SMS replying“ states of the pedestrian walk. The subjects experienced in a realistic 3D environment, subject to different walking experiences, and noted changes in EEG responses reflecting changes in cognitive status.

This study has more results about pedestrian distraction and behavior:

Significant changes were observed during pedestrian walking. Based on the paired the t-test, the walk of distracted pedestrians showed serious problems when about to reply to SMS.

Moreover, the experiment was applied to participants during and walking in PDVS to detect the performance of reply to SMS while walking (Standard Deviation 4.43; Mean 12.14,) and when not replying to SMS while walking (Standard Deviation 3.99; Mean 16.12,).

The relationship between the two conditions was analyzed by the Paired t-test. Intensive activity was observed in the frontal lobe as participants responded to SMSs so this result corresponded with frontal lobe activities.

Table 1 and Table 2 includes the changes in mean and standard deviation on the left/right frontal lobes during both the distracted walking and non-distracted walking sessions, while performing the “read task” and “reply task.”
### Table 1. Mean and standard deviation of EEG data at different tasks in right frontal lobes

<table>
<thead>
<tr>
<th>Bands</th>
<th>The Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Distracted</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>Alpha-1</td>
<td>107,965.74</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>Alpha-2</td>
<td>104,444.21</td>
</tr>
<tr>
<td><strong>L</strong></td>
<td>Beta-1</td>
<td>89,241.77</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>Beta-2</td>
<td>315,457.75</td>
</tr>
<tr>
<td>Theta</td>
<td>156,443.42</td>
<td>215,870.14</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>Alpha-1</td>
<td>49,101.24</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Alpha-2</td>
<td>32,457.78</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>Beta-1</td>
<td>66,777.14</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Beta-2</td>
<td>284,147.18</td>
</tr>
<tr>
<td>Theta</td>
<td>112,788.11</td>
<td>179,888.12</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>Theta</td>
<td>27,478.77</td>
</tr>
</tbody>
</table>

### Table 2. Mean and standard deviation of EEG data at different tasks in left frontal lobes

<table>
<thead>
<tr>
<th>Bands</th>
<th>The Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Distracted</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>Alpha-1</td>
<td>69,478.45</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>Alpha-2</td>
<td>75,998.87</td>
</tr>
<tr>
<td><strong>L</strong></td>
<td>Beta-1</td>
<td>116,478.14</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>Beta-2</td>
<td>489,479.99</td>
</tr>
<tr>
<td>Theta</td>
<td>136,145.47</td>
<td>161,147.12</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>Alpha-1</td>
<td>264,233.09</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Alpha-2</td>
<td>318,443.21</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>Beta-1</td>
<td>272,333.44</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Beta-2</td>
<td>589,178.04</td>
</tr>
<tr>
<td>Theta</td>
<td>189,478.12</td>
<td>310,149.15</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>Alpha-1</td>
<td>30,147.12</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Alpha-2</td>
<td>343,479.12</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>Beta-1</td>
<td>110,997.37</td>
</tr>
<tr>
<td><strong>L</strong></td>
<td>Beta-2</td>
<td>575,418.23</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>Theta</td>
<td>364,479,14</td>
</tr>
</tbody>
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On the other hand, the comparison between the task-1 and task-2 using paired t-test for the alpha and theta band indicated meaningful differences (p<0.05) for each other. Especially in the SMS reply, the alpha band has been increased. In addition, intense activity was observed in the frontal lobe in distracted walking (Figure 4).

In addition, much more density was observed in the theta bands (F3, F4, FC6, FC3) of those who correctly answered SMS reply. In participants who responded incorrectly to SMSs, these densities are less in frontal regions. It is known that the F3 and F4 channels increase in intense emotional states and in election stages (Ohme et al., 2010; Khushaba et al., 2012). However, on the F3 channel has been get information when SMS reply and SMS received. On beta channel; although SMS is taken and activities are observed when the correct answer is given; When the SMS was answered incorrectly, these activities were not encountered. This can lead to the result that the beta channel can be active in thoughtful answers.

Also, participants who are called distracted that observed a density in the frontal lobes during the accident. Beta exhibited that highest information at FC6 and AF4 when pedestrian just read a SMS. Interestingly, this is an activity that occurs in the right lobe of the brain. Theta bands also highest score on F3 with read SMS and on F4 with reply SMS. Besides that experiments showed that both theta and alpha are the least inconsistent
values of mutual information obtained by both reading and replying preferences. Hereby, the harmonization of the alpha and theta bands in answering SMS concerns preferences in decision making.

4. Discussion

The use of mobile phones is rapidly growing worldwide. In Canada, the percentage of smartphone owners has increased from nearly 20% in 2011 to 54% in early 2012 (PA, 2012). The negative impact of mobile phone use on drivers’ safety has been demonstrated (Horrey and Wickens, 2006; Drury et al., 2012). However, the safety hazards related to mobile phones do not apply only to drivers. A large number of road accidents involve pedestrians distracted by their phones. In addition, many fatalities among pedestrians are due to inattention (Bungum et al., 2005). Most studies have addressed this problem through observational research paradigms (Stavrinos et al., 2009; Hyman et al., 2010) but few have systematically studied the impact of mobile communication technologies on a user’s attention while walking.

In addition all, as mobile phone subscriptions have increased by 20 million per year since 2000 (Hatfield and Murphy, 2007), we would expect to find a further increase in the number of injuries among pedestrians using mobile phones (Nasar & Troyer, 2013). According to CTIA-The Wireless Association (CTIA, 2011) the mobile industry’s trade association, approximately 75 billion SMS texts were sent in June 2009. Another study conducted by the University of Birmingham focused on children using cell phones and found out the following (OC, 2010):

- “Students using cell phones took up to 20% longer to cross the street than children who were not using cell phones;
- Slow-crossing students with cell phones were up to 43% more likely to be hit by a vehicle while crossing the street;
- When using cell phones while crossing the street, children looked both ways 20% fewer times”.

Birmingham study is a clear indication of how smart our life has entered our life. In this sense, the best way to deal with the situation is; to look for any safe ways to use it. The important thing is to be able to reveal the cognitive situations that arise when the mobile phone is used. As Nasar
and other researchers found reduced situation awareness and distracted attention among pedestrians using mobile phones (Berka et al., 2004; Nasar et al., 2007; Nasar et al., 2008; Stavrinos et al., 2011; Jatoi et al., 2014). For drivers, pedestrians who are distracted by cell phone use threaten their safety. EEG is the most valid tool for measuring attention distribution and has the advantage of a high temporal resolution allowing carrying out cognitive tasks (Klimesch et al., 1998). This study is focused on these channels because there is good data on the widely accepted cognitive distribution in EEG measurements that they are theta, alpha and beta (Schier, 2000). The alpha band is considered to be the dominant band in the attention tendency (Rowland et al., 1998;). Theta and beta activities can be regarded as stimulants of many cognitive functions, especially in the frontal lobe of the brain. These activities are related to mathematical problem solving, working memory and decision making (Wolfgang, 1999). Especially in the study, it was seen that alpha activity was effective immediately on SMS reply. In fact, this is also the stage of decision making in a sense. However, it was observed that the participants spent a lot of time and attention at the lowest levels.

In addition to these, there have been several studies on emotion recognition by EEG. It is also Nidal and Malik (2014) stated that the alpha wave is effective in attention and semantic memory processes The intensity of the activities seen in the frontal lobe was also seen at the most intense level at the time of SMS reply.

The increase in the upper-alpha band during the tasks at the de-synchronization but there was no increase in the band (Greenfield et al., 2012). It has been found that upper alpha signals rise in the order of both receiving and replying SMS. Furthermore, when a reduction in alpha power shows that a certain relative has a high level of attention, an increase in the power of the theta indicates that it distracts a particular task (Neider et al., 2010). Hereby, it has been found that the alpha and theta waves of female participants in particular rise at the moment of the SMS they reply when they walk. This may mean that women are even more careless when replying SMS.
5. Conclusions

This study shows that pedestrians have a significant effect on walking cognitive performance and certain cognitive situations as reading and replying SMS.

Significant changes in the amplitude of EEG were observed in the left and right frontal lobes when and pedestrians used mobile phones while they walked. These changes during walking were especially in the theta band and SMS response time in frontal lobe. Also, this increase in the theta can be thought of as a sign of distraction; a significant increase of the alpha may be regarded as a sign of attention. At the same time, changes were recorded in the beta (both 1 and 2) during read and reply SMS tasks.

EEG data shows that replying SMS is more effective in brain activities than received SMS. The replying SMS task had a high impact on the pedestrian cognitive status as a „serious distraction“.. The right frontal lobe was detected as the most disturbed area, especially when SMS was responded. Interestingly, no significant change in walking on the left frontal lobe was observed.

This study analyzes the changes in the cognitive state of pedestrians and also provides physical data on different cognitive tasks using EEG. This study showed tangible data that the attention distribution of pedestrians who walk while using mobile phones was determined by EEG, a method of brain measurement. One of the most important results of the study is that an ongoing response is recorded in the middle of the prefrontal cortex in those who are careless walking.

In many cases, when pedestrians use the sidewalk, they are faced with many situations such as foot tease, stumbling, or an unnoticeable incoming vehicle. Mobile phones distracted college student pedestrians, as supported by Stavrinos et al. (2009). In September 2012, in response to a growing awareness of pedestrian distraction, the New York City Department of Transportation launched the LOOK! Likewise, San Francisco adopted a huge media blitz that warned walkers about the dangers of headphones while walking (NYC, 2014). Also, some signs on the pedestrian walkway (attention, look at the light, etc.), which were used in the simulator, have been observed to draw the attention of pedestrians.
Distraction increases crossing time and unsafe walking, affects crossing/walking behaviors, and puts pedestrians at a greater risk. The findings of this research suggest the need for interventions to decrease the use of mobile phones while walking and increase the attentiveness of all pedestrians on streets. Many institutions that care about pedestrian carelessness increase their measures for this. In Augsburg, Germany, proposed a solution that could draw the attention of the transport sector regarding the distraction of pedestrians. “The city has attempted to solve that problem by installing new traffic lights embedded in the pavement — so that pedestrians constantly looking down at their phones won’t miss them” (Washington Post, 2016). It seems that by developing new design methods; It is necessary to recreate the walking paths and the streets. In this way, it will be possible to provide the safety of the pedestrians with these design methods.

Further studies on other brain analysis methods with specific criteria are warranted. If it is to be tested with an EEG can be created as virtual spaces. In the future, a similar study on real-world methods, such as instant f-MRI, FNIRS, is suggested because EEG measurement of brain activity of mobile people can be difficult.

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**Conflicts of Interest:** “The author declares no conflict of interest.

**Appendix A: SMS Questions**

1- *Who is the first president of Turkey?*
   A-Mustafa Kemal Atatürk
   B-İsmet İnönü
   C-Süleyman Demirel
   D-Turgut Özal

2- *Who is the best player of NBA?*
   A-Barrack Obama
B-Hilary Clinton  
C-Lionel Messi  
D-Michael Jordan

3-if 5 eggs is 5 pound, 25 eggs that how much is that?  
A-5  
B-10  
C-15  
D-25

4-Which one is different?  
A-Apple  
B-Banana  
C-Strawberries  
D-Pear

5-If you rearrange the letters “MIRZI” you would have the name of a(n)?  
A-CITY  
B-ANIMAL  
C-OCEAN  
D-MOVIE

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